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# STEEL CATENARY RISERS IN DEEPWATER ENVIRONMENTS

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## INTRODUCTION

The STRIDE JIP was initiated by 2H Offshore Engineering and BP in Spring 1997 to investigate aspects relating to deepwater steel catenary risers (SCR's). The bulk of the work has been associated with *welded* steel risers, and whilst these may appear to be simple extensions of the seabed pipeline in terms of installation and design aspects, special design considerations must be applied.

Phase I of STRIDE performed detailed analysis of riser configurations and looked closely at installation issues [1]. Key areas for further investigation were then taken into Phase II, including:

Vortex Induced Vibration (VIV)
Riser welding and fatigue issues
Riser Touch Down Point (TDP) behaviour

Whilst a number of SCR's had already been deployed at the start of Phase II, STRIDE was looking to confirm design criteria, reduce design conservatism and reduce development costs, a popular view judging by the level of industry sponsorship for the project.

STRIDE Phase II completed in December 1999. This paper describes the prime areas of interest, together with how this work is now being developed within STRIDE Phase III.

## SCR VIV INVESTIGATION ACTIVITIES

Deepwater developments often involve significant ocean currents over great water depths. It has long been known that vertical riser pipes shed vortices that can cause the structure to resonate – this vortex induced vibration (VIV) can rapidly produce high levels of fatigue damage. The use of helical VIV strakes has been well proven for vertical structures, but for catenary risers there are additional issues, in particular:

- whether strakes supress VIV on highly inclined or curved structures
- the significance of the strake drag penalty when the riser is highly compliant and subject to deflection forces
- whether strakes are even required for highly inclined or curved structures, i.e. whilst a vertical structure can have consistent VIV tendency over its whole length, and can therefore resonate with great power, a curved or inclined riser will have many interacting natural vibration modes, with “power-in” and “power-out” regions interacting.

STRIDE Phase II investigations involved tow tank work and large scale tests at sea.

**VIV Tow-Tank Tests**

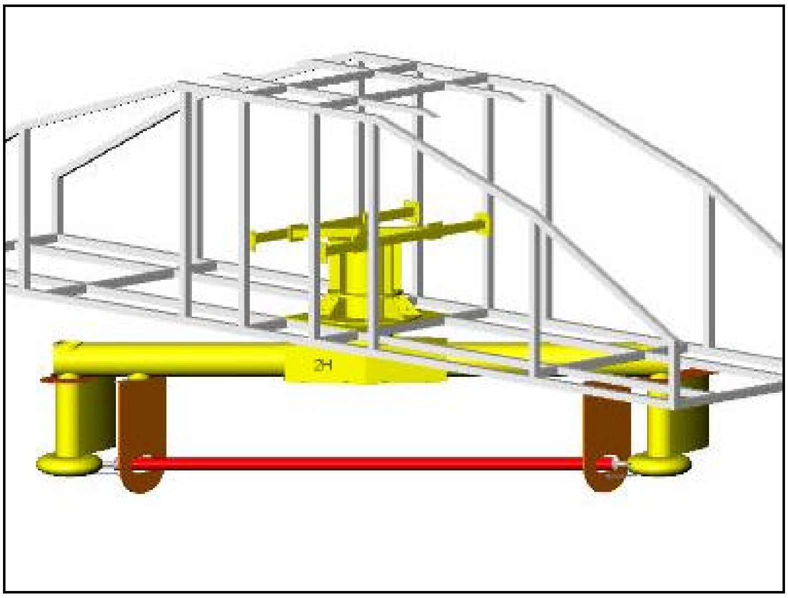

**Figure 1.1 – Tow-tank Rig**

6m long riser models were towed in a tow tank to simulate sections of a catenary riser exposed to ocean currents. 6” and 3” diameter pipes were towed at angles up to 45$^{o}$ to the tow direction, at speeds reaching 5 m/s, and with different levels of VIV straking (the lower horizontal pipe in Figure 1.1).

Results indicated that for a system with just a few resonant vibration modes, VIV occurs with frequency according to analytical prediction, but amplitudes about half those expected. This amplitude reduction may have been due to damping within the model set-up, or because the testing was being conducted largely in the critical Reynolds Regime. Modes 1 and 2 were clearly seen.

It was found that for incidence angles up to 30$^{o}$ (where 0$^{o}$ represents a vertical riser) the VIV response could be predicted by using the resolved current normal to the pipe. For the maximum angle of 45$^{o}$, VIV amplitude response was higher, but this may have been due to end effects from this extreme angle.

Straking was found to be effective at all angles. Bare and straked pipe drag coefficients were measured at different speeds and angles, and found to be largely as expected, **except** that in the critical Reynolds regime, the dip in the drag curve was found to dominate and mask any VIV drag effects.

Single hand rotation helical strakes were found to provide a significant torque as riser angle increases. This was shown to produce a displacing force on the curved test pipes, either arching them upwards or downwards, depending on the hand of the helix.

**Open Water VIV Tests**

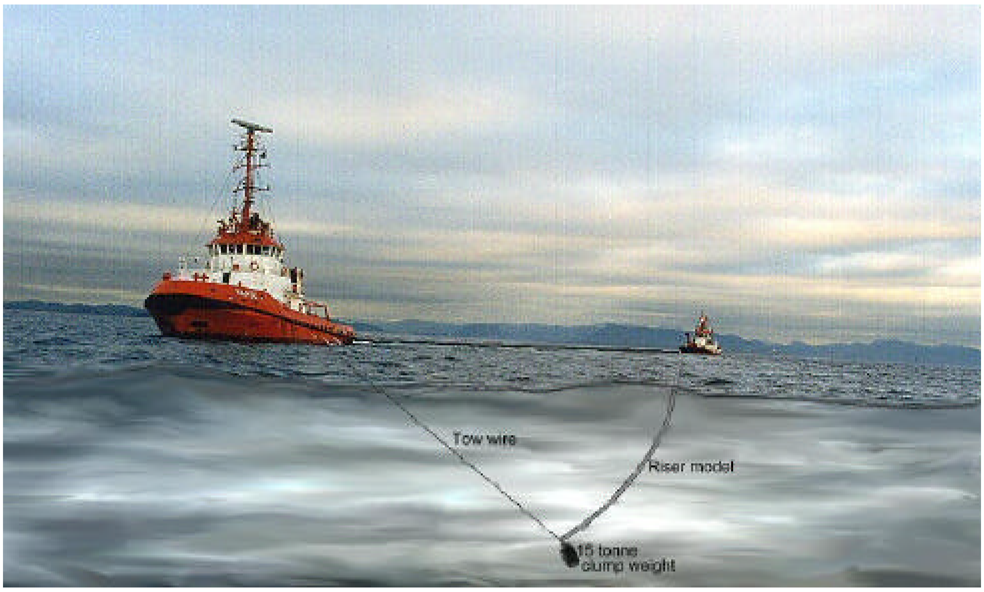


**Figure 1.2 – Open Water Tow Schematic**

The most ambitious Phase II activity was the open water test programme, where two 200m long 10" diameter steel pipes were towed at different angles and speeds between two tugs in a fjord. One pipe was "bare" (as welded) and the second had a 3-start helical strake system, designed, supplied and fitted by 2H. Speeds up to 5 knots were achieved, and by adjusting the tow rigging, highly curved and shallow angle riser sections were simulated.

2H accelerometer bottles were used to measure VIV response at 40 locations along each pipe. Drag was measured using tension load shackles, and other instrumentation measured pipe rotation and elevation.

Detailed results from this activity are currently restricted to STRIDE II participants. It can be reported that VIV was lower than that expected from theoretical prediction based on straight and vertical risers. The strake system was effective at virtually eliminating this vibration.

**Figure 1.3 – Lifting out the Straked Pipe**

## SCR Welding and Fatigue Issues

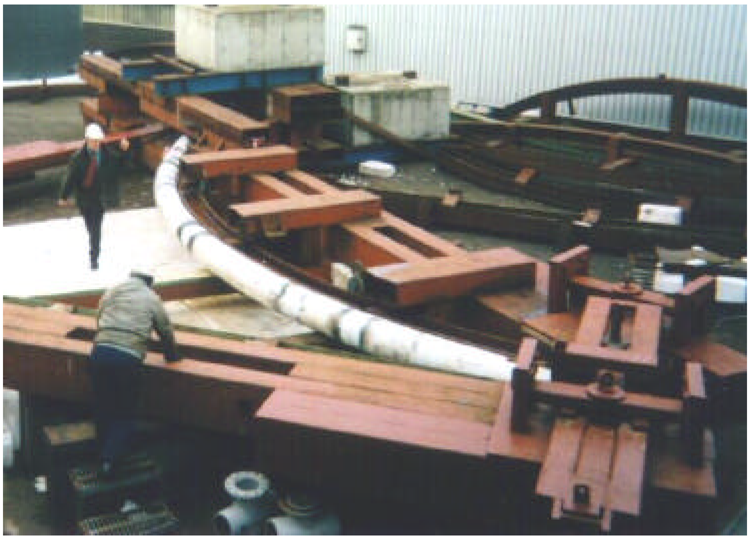

**Figure 1.4 – Reel Simulation of Riser Pipe**

Offshore catenary risers are required to transport high pressure fluids under highly dynamic loading for many years, and the welds in particular require a high level of fatigue damage resistance. In addition, offshore pipe reeling is seen as an attractive and economical method for SCR installation, allowing factory welding and NDT, and fast installation to make use of tight weather windows. This investigation assessed the fatigue life of SCR welds, including welds that had been subject to extreme plastic strain from simulated reeling cycles.

12.75” diameter pipes were welded and inspected using procedures developed during STRIDE Phase I. No special pipe end matching, machining or weld dressing was used, though NDT procedures were stringent. Some of the pipes were then bent and back-bent on a jig designed to simulate the high plastic strains of a reeled installation procedure (Figure 1.4). This included simulation of an abandonment/recovery operation offshore, where adverse weather during an installation campaign may require the pipe to be reeled out in a hurry and suspended on a wire, and then reeled back in to continue controlled laying.

Fatigue testing was then conducted at TWI Cambridge. 15 full size girth welds were taken to failure, 15 others were not failed but fatigue lives could be estimated from crack measurements.

It was found that no significant fatigue life reduction resulted from the plastic straining on these tests. In addition, the fatigue lives of the welds, both plastic strained and as-welded, were all found to achieve DnV class E or API class X’, higher quality than curves that are normally considered appropriate for single side girth welds.

It is to be emphasised that results such as these are based on specific weld and NDT procedures, pipe geometry, steel properties, etc. which were chosen as representative and typical of SCR developments. However, this and the limited number of samples tested may mean that such results may not be applicable in other cases.

**TDP TANK TESTS**

In a commercial water tank, small scale tests were performed with a 32m long ¼” diameter pipe allowed to drape across the tank bottom which was arranged to provide either a rigid or soft seabed simulation.

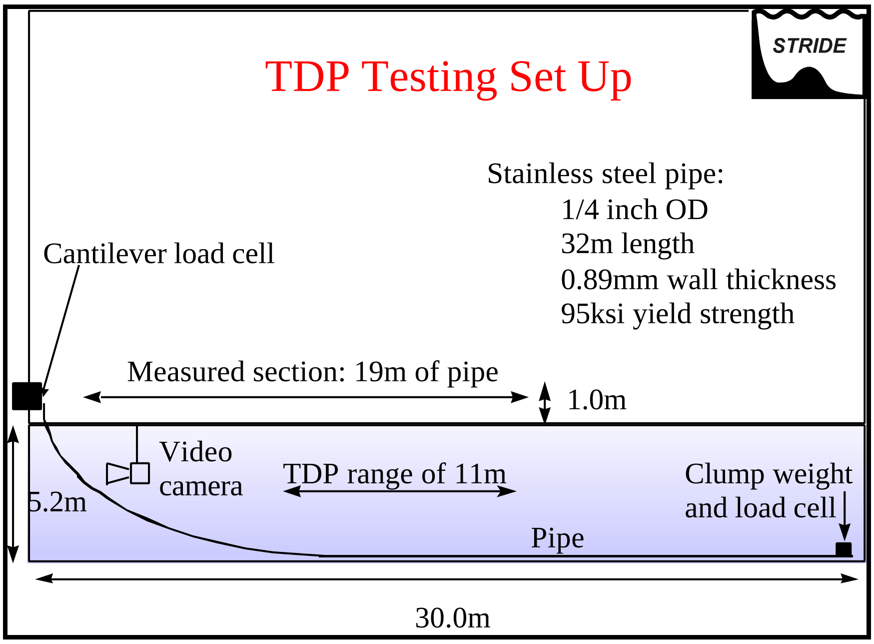


**Figure 1.5 – TDP Tank Tests**

Actuating the pipe at the top end simulated exaggerated vessel motions, and by monitoring the pipe response a comparison was possible with analytical prediction for motions and stresses. Of particular interest were riser buckling and out-of-plane motions as riser tension is lost due to extreme top end motions. With the right FE modelling parameters, Flexcom and Riflex were both found to predict the response well.

**STRIDE PHASE III**

STRIDE Phase III is now funded and kicked off with an extensive programme of activities over the next 11 months. One of these, the TDP/soil interaction programme, is described here:

Inspection of offshore SCR's has revealed deep trenching in the dynamic TDP area, with evidence of back-fill and multiple trenches near the TDP departure point. The STRIDE III test objective is to increase the understanding of SCR/seabed interaction in terms of local riser stresses and trench mechanisms by setting up a large scale 3D test arrangement.

A 100m long 6" diameter pipe will be actuated from a harbour wall to simulate the bottom 5m depth section of a deepwater catenary riser (Figures 1.7, 1.8). A location has been found that has seabed geotechnical properties similar to those of a deepwater Gulf of Mexico seabed. The harbour is tidal ranging from empty to 5m water depth, and this ability to test with and without water provides an opportunity to isolate and combine a number of effects:

- soil suction and stiction effects on riser peak stresses
- hydrodynamic suction and pumping effects on riser peak stresses
- trench formation mechanisms
- trench influence on riser behaviour and stresses
- verification of analytical tools (soil-loading curves)

**Figure 1.7 – Harbour TDP Tests (modified photograph)**

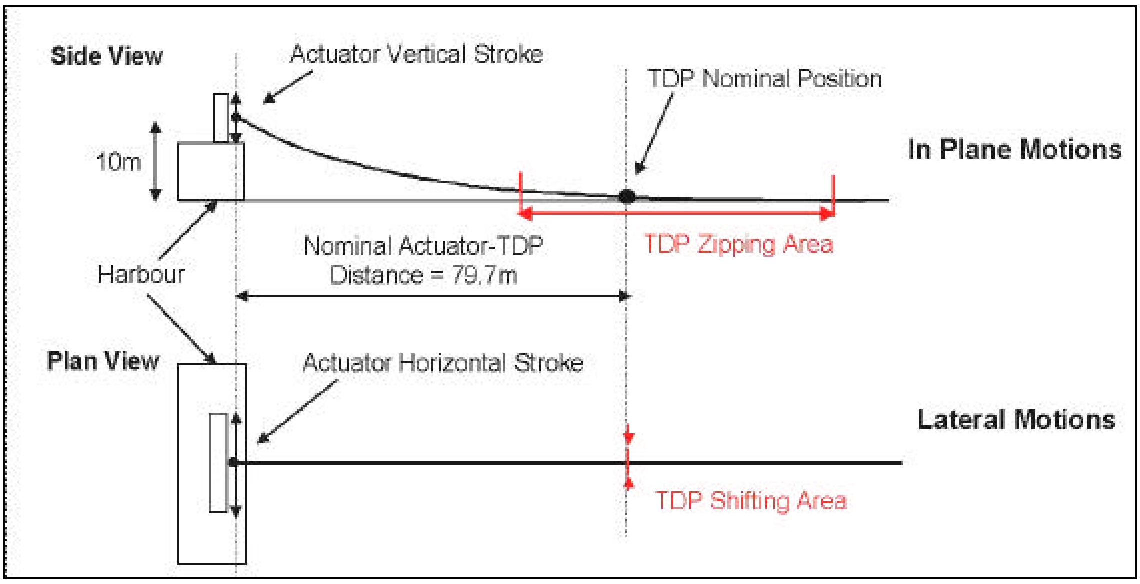


**Figure 1.8 – Test Schematic**

Preparation for the test programme is progressing well, and tests will be performed in the Spring of this year.

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**STRIDE Phase II Lead Engineering Contractor:**

*2H Offshore Engineering*

**Oil company participants in STRIDE Phase II:**

*ARCO*
*BHP Petroleum*
*BP Amoco*
*Chevron*
*Conoco*
*Elf*
*Enterprise Oil*
*Exxon Production Research*
*Mobil North Sea*
*Norsk Hydro*
*Saga Petroleum*
*Shell UK Exploration & Production*
*Statoil*
*Total Oil Marine*

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*ETPM*
*Single Buoy Moorings*
*Sofec*
*Stolt Comex Seaway*

**Program manager STRIDE Phase II:**

*Offshore Technology Management*

References

[1] “Steel Catenary Risers for Deepwater Environments” OTC 8607 1998
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